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Rain Water for Domestic Purposes

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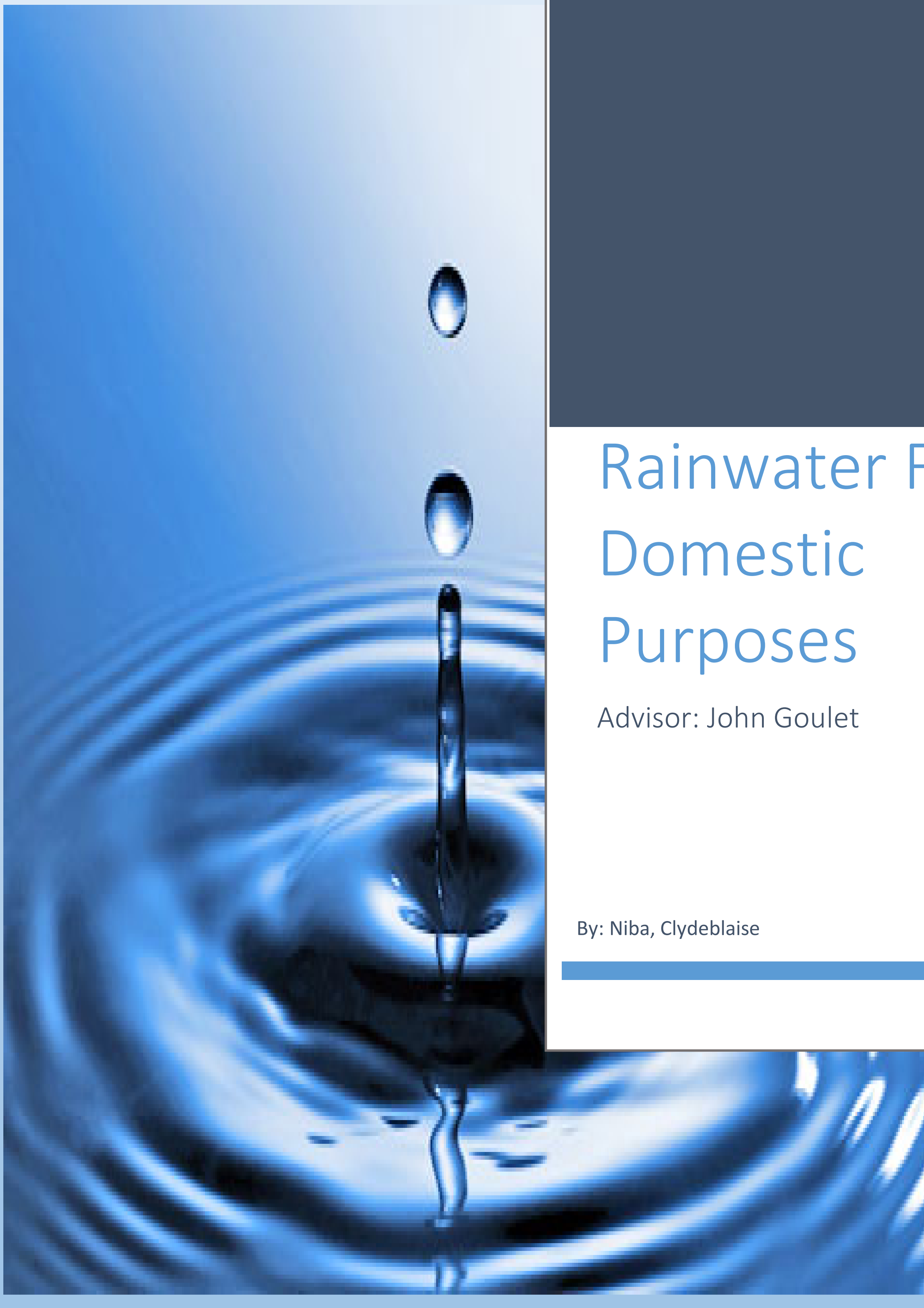

Rainwater For Domestic Purposes

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WORCESTER POLYTECHNIC INSTITUTE

RAINWATER FOR DOMESTIC PURPOSES

Developing a system for harvesting rainwater

An Interactive Qualifying Project Report submitted to the faculty of
Worcester Polytechnic Institute
In partial fulfillment of the Degree of Bachelor Science

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On campus Worcester Project Center

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Abstract

This project deals particularly with figuring out a way to take rainwater that comes down gutters and recycle it into reusable water for domestic purposes such as, doing laundry or flushing the toilet. The process includes learning and researching what kind of chemicals are in rainwater, but also where it ends up if it is not being recycled. Also, being able to understand the amount of precipitation that falls throughout the year, and which month has the highest precipitation is important in determining how large of a storage tank you would need for storing the rainwater.

Acknowledgment

I would like to extend a special thanks to the following individuals for their continuous support throughout my project.

Advisor John Goulet:

Provided guidance throughout the entire project, by guiding me toward the right direction as to what he expects to get accomplished.

Ryan Cain:

As a Civil Engineer, with about 8 years of experience working with waste water, Cain was able to explain the process of recycling the rainwater through different pumps and filters that could be used.

Jon Pellegrino:

Works for the Environmental engineering department at Worcester Polytechnic Institute, and advised me on information about water testing, particularly rainwater.

1. Executive summary

1.1 Introduction

Gives a description about what my project was about, which is Rainwater treatment for domestic purposes. Explains the reasoning behind my research and the overall goal of the project, which is to figure out a system to covert rainwater into reusable water back into a home, for purposes such as flushing the toilet or doing laundry.

1.2 Background

Provides information about the location of were the project site is located, which is Central Massachusetts. Important information which I needed to know in order to figure out the kind of equipment's I would need to eject groundwater or capture rainfall. I also did the same research for the state of California, just to compare it to some cities in Massachusetts to get a geographical comparison on the amount of Rainfall which Massachusetts receives.

1.3 Methodology

Explains the process and journey I took throughout the project in order to figure out the best system I could use to capture rainwater from a home and then use it for domestic purposes. The section also explains most of my mistakes and some of the systems I found but where not the best once to use. Furthermore it describes these systems and gives a good description of how to obtain the systems if someone was interested in purchasing them.

1.4 Results and Analysis

The readers can view all the statistical analysis and results that I found throughout the project. This section includes data tables that represent the results for precipitation in some cities in Central Massachusetts and also California. Also the section includes the final system that residents could use to extract rainwater from their rain gutters to use for domestic purposes such as flushing their toilet or washing their cars.

1.5 Conclusion

Demonstrates some of the uses for rainwater and most of all, the advantages of it. Describes why more people should take advantage of harvesting rainwater and save money on their water bill. This section also explains what I have learned while working on this wonderful project.

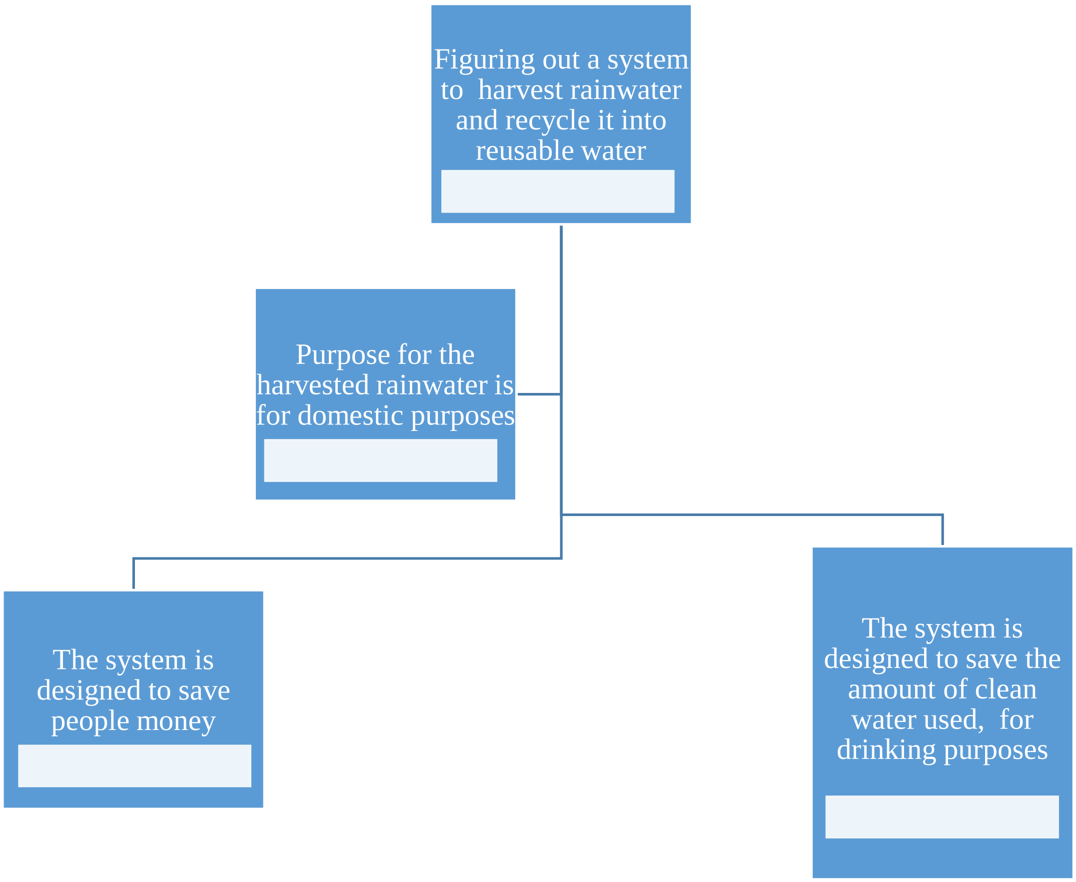
1.6 Figures

1.7 Tables

Table of Contents

Contents

2. Project Objective



3. Introduction

In order to treat rainwater for domestic purposes, you have to understand what is in it, and therefore figure out what kind of system you need to help recycle the water. My advisor John Goulet, who is a Teaching Professor, a Mathematical Science Director, and also is the Teacher Preparation Program coordinator at Worcester Polytechnic Institute gave me the task of coming up with a system that he can use to turn the rainwater that comes out of his gutters into domestic purposes such as flushing the toilet or doing laundry at his home. The same process will and can be used from any resident rain gutters as long as there is rainfall. Professor Goulet also wanted to test the process, by setting up this system in his garage and using it to wash his car for beginner purposes, before heading into the final stages of building the system for his home. However, before I began researching what kind of particles are in rainwater, I had to first understand what the rainwater turns into when it is not collected. I also had to understand where the rainwater ends up, because I might be able to eject the water from wherever it is and possibly use it for domestic purposes as well. The Rainwater which is not captured, turns into (4.1) Groundwater, which then goes into (4.2) Aquifers. Additionally, I looked into some of the (4.3) uses of groundwater and the important questions I had to ask myself about ground water; such as, (4.4) what are the uses of ground water, (4.5) how to eject the ground water from aquifers, and also (4.6) if we can run out of groundwater. It was important to also know the amount of rainfall that happens each month in Central Massachusetts, which enabled me to figure out how big of a tank I would need to store the rainwater. It was also good to research another states rainfall level such as California and compare it to some cities in Central Massachusetts, because this way if you where someone depending on using rainwater for domestic purposes, you can know what region of the country to move into depending on the amount of rainfall the state gets.

3.1 Groundwater

As water seeps into the ground, some of it clings to particles of soil or to roots of plants just below the land surface. This moisture provides plants with the water they need to grow. Water not used by plants moves deeper into the ground. The water moves downward through empty spaces or cracks in the soil, sand, or rocks until it reaches a layer of rock through which water cannot easily move. The water then fills the empty spaces and cracks above that layer. The top of the water in the soil, sand, or rocks is called the *water table* and the water that fills the empty spaces and cracks is called *ground water* (“What is Ground Water”, 2015). Ground water is recharged from rainwater and snowmelt or from water that leaks through the bottom of some lakes and rivers. Also groundwater can be recharged when water-supply systems (pipelines and canals) leak and when crops are irrigated with more water than the plants can use furthermore, ground water can be found almost everywhere. Heavy rains or melting snow may increase recharge and cause the groundwater to rise. However, an extended period of dry weather may decrease recharge and cause the water table or level of groundwater to fall (“What is Ground Water”, 2015)

3.2 Aquifers

Aquifer

An Aquifer is a formation, group of formations, or part of a formation that contains sufficient saturated, permeable material to yield significant quantities of water to wells and springs (“What is Ground Water”, 2015). *Aquifer* is also the name given to underground soil or rock through which ground water can easily move as shown in *figure 1*. The amount of ground water that can flow through soil or rock depends on the size of the spaces in the soil or rock and how well the spaces are connected. The amount of spaces is called the porosity, and permeability is a measure of how well the spaces are connected.

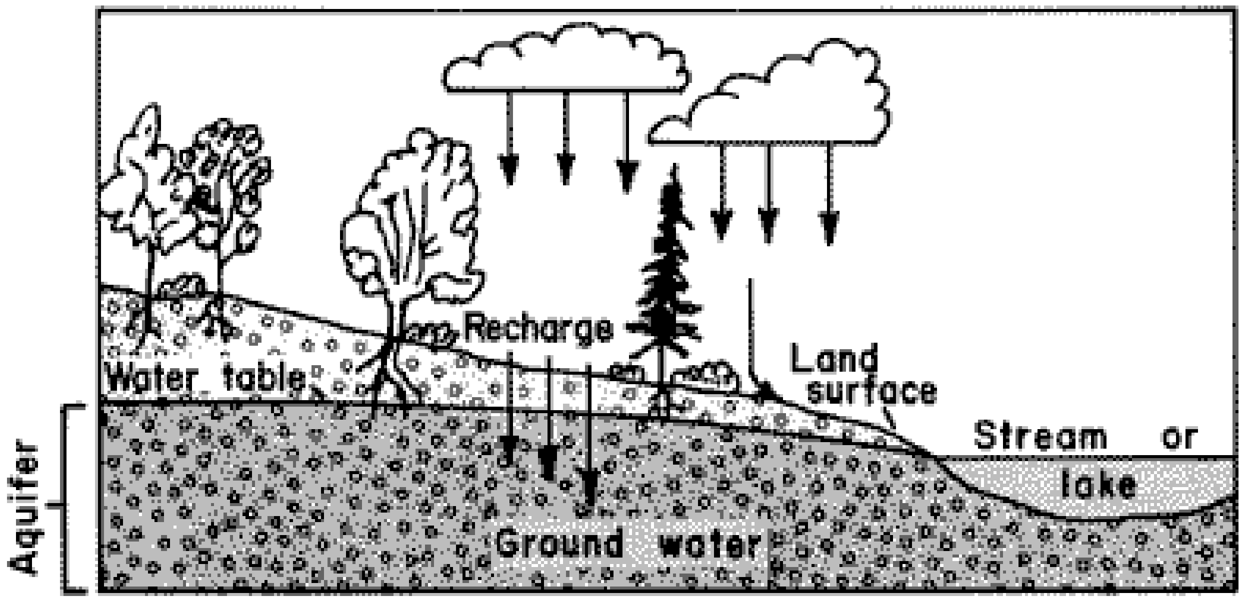


Figure 1: portrays all the possible process of groundwater in an Aquifer

Photo: USGS

3.3 How ground water moves

How the Ground water moves

Groundwater can move in two places, which are through gravel or rock. Gravel, such as clay need *open pores* for the water to be permeable Rock. For water to be permeable, spaces in the rock called *Fractures* are needed, as shown in *Figure 2* (“What is Ground Water”, 2015).

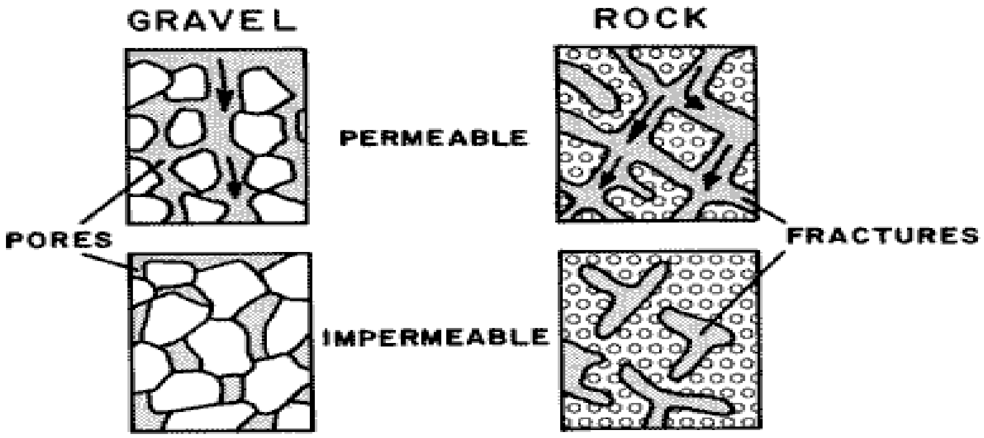


Figure 2: Portrays were ground is permeable and impermeable

Photo: USGS

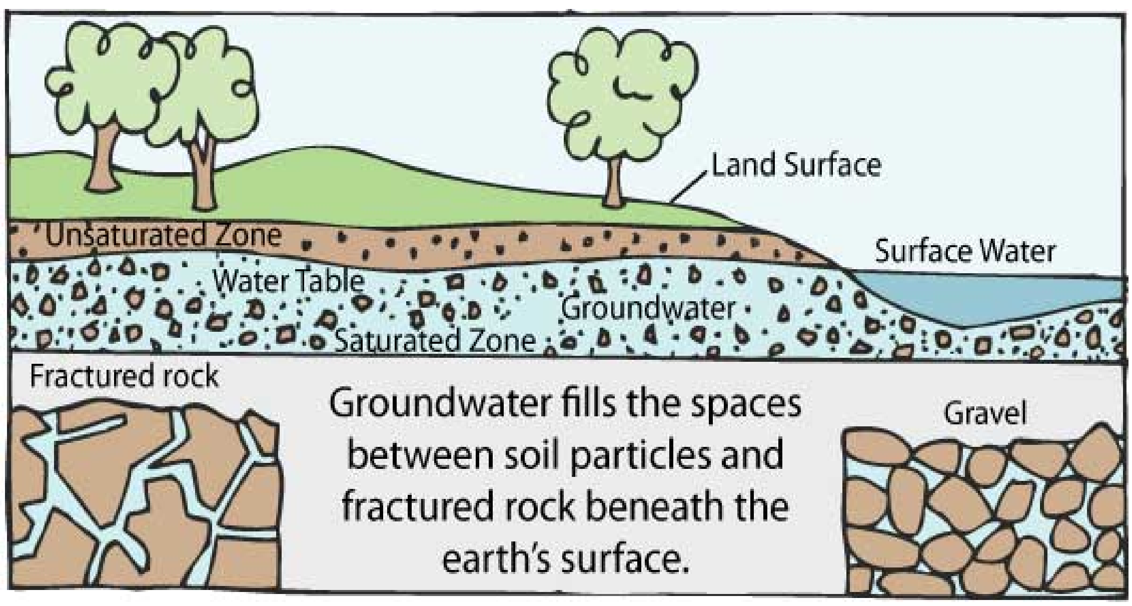


Figure 3: Portrays locations of ground, and the process it takes to get there

Photo: courtesy of U.S Geological survey

3.4 Use of Ground Water

Groundwater can be used for abundance of things such as, washing cars, watering plants or even doing laundry at home. More than 50 percent of the people in the United States, including almost everyone who lives in rural areas, use ground water for drinking and other household use ("What is Ground Water", 2015). Ground water is also used in some way by about 75 percent of cities and by many factories. The largest use of ground water is to irrigate crops, because groundwater mostly contains some nutrients that help these plants grow.

3.5 How to eject groundwater out of the Aquifers?

Ground water can be obtained by drilling or digging wells, in the aquifers; as shown in *figure3*. A well is usually a pipe in the ground that fills with ground water. This water can then be brought to the land surface by a pump. Shallow wells may go dry if the water table falls below the bottom of the well, as illustrated at right. Water leaving an aquifer is called discharge water ("What is Ground Water", 2015). Also, Ground water can become unusable if it becomes polluted and is no longer safe to drink. In areas where the material above the aquifer is permeable, pollutants can seep into ground water. Ground water can be polluted by seepage through landfills, from septic tanks, from leaky underground fuel tanks, and sometimes from fertilizers or pesticides used on farms as shown at right ("What is Ground Water", 2015).. We can run out of ground water if more water is discharged than recharged. For example, during periods of dry weather, recharge to the aquifers decreases. If too much ground water is pumped during these times, the water table can fall and wells may go dry ("What is Ground Water", 2015).

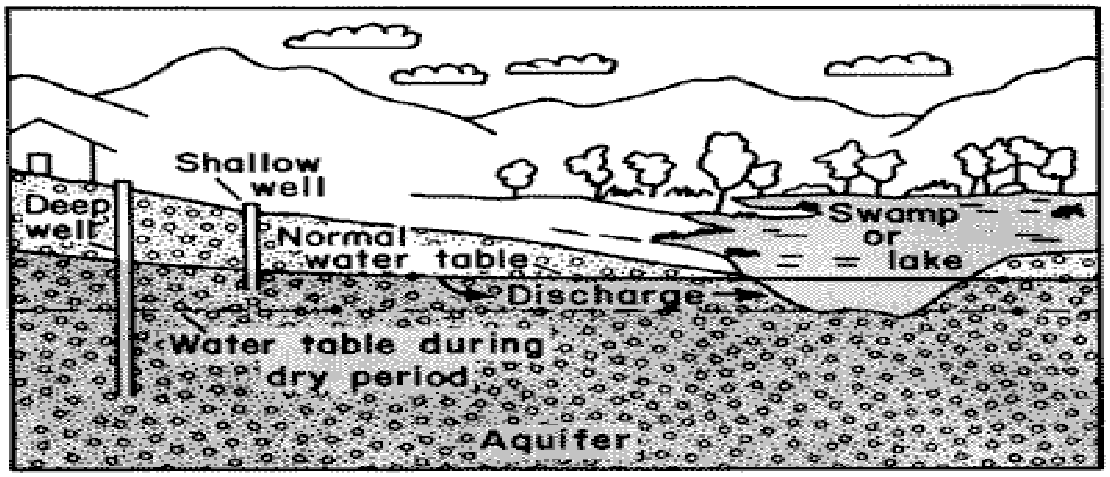


Figure 4: Different methods of ejecting ground water, from aquifers

Photo: USGS

4. Background

To get a better understanding of the kind of equipment needed to complete this project, I had to know more about Aquifers. I did abundant of research on the different kinds of Aquifers in Massachusetts, and compared it to another geographical location, which was California. Aquifers are different in terms of location and if we were looking to eject groundwater from them, I had to know what kinds of Aquifer I was dealing with.

4.1 Types of Aquifers in Massachusetts

Massachusetts: Alluvial aquifers and glacial aquifers

What are *alluvial aquifers?*

Rivers periodically overflow their banks, creating large, flat floodplains and often change their course during a flood, leaving behind oxbow lakes and meander scars. As the river channel swings back and forth across this floodplain, point bar deposits of sand and coarse gravel are left behind on the inside of meanders as the river erodes away the bank opposite these deposits. In general, coarse gravels are deposited in the stream channel, sand and fine gravel form natural levees along river banks, and silt and clay come to rest on the floodplain. (Fetter, 2001) The term used for these unconsolidated sediments, including clay, silt, sand and gravel, deposited by flowing rivers is called *alluvium*.

What they do:

The alluvial aquifer systems provide a valuable source of groundwater to surrounding communities, while the surface alluvial features provide excellent soils for agricultural purposes. Because of the importance of these regions, monitoring them is essential, but as was demonstrated by this project, the data must be analyzed critically and carefully (Fetter, 2001)

What are *glacial aquifers*?

Glacial deposit aquifers consist mostly of clay, silt, sand, and gravel in various combinations, but also include cobbles and boulders (Fetter, 2001).

What they do?

Glacial-deposit aquifers form numerous local, and some regional, highly productive aquifers in the area north of the line of glaciation. These aquifers consist of outwash, terrace, or ice-contact deposits, and they mostly occupy bedrock valleys or areas of ice marginal deposition. In places, the valley deposits are buried beneath low-permeability till. Groundwater flow in the glacial-deposit aquifers is primarily local, from recharge areas near stream valley walls to discharge in the streams. (Fetter, 2001).

4.2 Types of Aquifers in California

California (unconsolidated sand and gravel aquifers)

Mainly unconsolidated sand and gravel aquifers can be grouped into four categories: basin-fill aquifers, which also are called "valley-fill aquifers"; blanket sand and gravel aquifers; glacial-deposit aquifers; and stream-valley aquifers which are of generally small extent and not mapped ("Natural Aquifers Code Reference list", 2016).

Basin fill Aquifers:

The hydraulic conductivity of the aquifers is variable, depending on the sorting of aquifer materials and the amount of silt and clay present, but generally it is high. Aquifer thickness ranges from a few meters or tens of meters in the blanket sands along the eastern Atlantic coast of the United States to several hundred meters in the basin-fill aquifers of the southwestern United States ("Natural Aquifers Code Reference list", 2016).

What are *Basin fill aquifers* for?

Some basin-fill aquifers, such as those in the Central Valley aquifer system of California and in parts of Arizona, have supplied large amounts of water for irrigation and other uses. Groundwater in these aquifers flows along relatively short flow paths typical of local flow systems; however, all of the basin-fill aquifers have intermediate flow systems, and the thick basin fill of California's Central Valley aquifer system has a regional flow system ("Natural Aquifers Code Reference list", 2016).

5. Methodology

At the beginning of the project, I had to do research on what groundwater was and where groundwater usually ends up, if people do not use it for domestic purposes or for irrigation purposes. Found out that groundwater usually ends up in aquifers, and based on the geographical region there are different forms of aquifers. It was important to know what kind of Aquifer I was dealing with in Central Massachusetts if I planned on ejecting the ground water from these aquifers. I then researched the amount of rainfall for the past 20 years in Massachusetts and also compared it to California as shown in Tables 1 and 2 of the results and analysis section below. To get a better estimate of how much water is produced by rainfall in each state, I took the annual rain fall in inches and calculated how many gallons per square feet. Then figured out how many gallons a year was produced each month in these states on excel, which is portrayed in Tables 1 and 2(insert calculations) Based on this information, it turns out California receives abundantly less rain than the cities in Massachusetts, therefore producing less gallons of water per year. This also portrays that if you are a resident looking to use rainwater for domestic purposes, Massachusetts would be a better state to reside in than California.

Based on the information provided in Tables 1 and 2, it is obvious that Central Massachusetts produces plethora of rainfall, so my advisor John Goulet suggested to focus on searching for a system that would obtain this rainwater from his home, store it and convert it into reusable water for domestic purposes. We both agreed that based on the amount of rainfall that occurs in the city of Worcester, Massachusetts, the pump we need should be about 110 voltages and handle at least 40psi.

5.1 Code of Massachusetts regulations

First I had to research if we needed a license to be able to use a system like this to reuse rainwater. Based on the code of Massachusetts regulations handbook, it proved we needed one depending on the amount of water we plan to harvest; for instance, “The construction, installation, operation, and maintenance of a treatment works, that treats wastewater so that it may be discharged to the ground in accordance with 314 CMR 5.00 and/or used as reclaimed water requires a permit issued by the Department pursuant to 314 CMR 5.00” (“Code of Massachusetts Regulation”, 2016). Although the amount of waters just for a single home a permit is not needed but you get a permit just to be on the safe side, although you are just using the reclaimed water for home purposes.

5.2 Things you have to worry about

There were also abundant of things I needed to worry about while working on this project. First was the contaminants or things in rainwater that could be extremely harmful. Germs and Other Contaminants in rainwater include dust, smoke, and soot from the air which can be dissolved in rainwater before it lands on your roof. Roofing materials, gutters, piping, and storage materials can introduce harmful chemicals like asbestos, lead, and copper to the rainwater coming down your rain gutters, though building standards minimize some of this (“Center of disease control and prevention”, 2013). Bird waste from the roof might be in the water, so apparently I would need some kind of filtration system to help remove or limit these things from entering the pump. Since I would need some kind of tank to store the rainwater in, there are Chemical components that I would need to worry about such as chloride, sulfate, sodium, potassium, ammonia…etc. Additionally, I had to take into account things living and growing in the container. The ability for something to grow in the container is huge and the major organism is E.coli. The solution to most cases is to put a certain amount of chlorine in the Tank, which stops the growth of E.coli ("Center of disease control and prevention", 2013). Also had a chance to speak to Jon Pellegrino, who works at Worcester Polytechnic Institute and is in charge of water testing at Kaven Hall. He said if my main use of the rainwater is doing laundry or flushing the toilet, then he thinks there's not a lot to worry about with the water. He thinks the only thing I might need to test is the PH level of the rainwater to make sure it's ok and get some kind of simple filtration system.

6. Results and Analysis

6.1 Central Massachusetts(MA) City Precipitation results for the last 25 years

Table 1.1: City of Leominster, MA precipitation data for the last 25 years (inches)

Central MA																				
Total Monthly Precipation data in Inches																				
STATION	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual	CITY	Region Co	Region	Basin Name	Gallons/sqaure foot	Gallons/year
LEO517	1990	4.04	1.56	0.83	4.45	6.61	1.53	1.8	5.78	1.86	7.9	2.22	4.32	42.9	Leominster		Central	NASHUA	25.74	41184
LEO517	1991	0.84	1.86	3.89	3.37	4.31	3.2	2.02	9.23	6.31	2.33	5.39	4.11	46.86	Leominster		Central	NASHUA	28.116	44985.6
LEO517	1992	2.99	2.12	3.43	2.42	4.48	3.85	3.29	5.98	1.64	1.94	5.88	4.45	42.47	Leominster		Central	NASHUA	25.482	40771.2
LEO517	1993	3.33	2.09	5.36	5.06	1.89	1.38	1.82	2.05	6.89	4.22	4.11	4.26	42.46	Leominster		Central	NASHUA	25.476	40761.6
LEO517	1994	2.95	1.45	5.38	6.96	6.47	2.64	4.57	5.39	5.06	1.11	1.94	5.66	49.58	Leominster		Central	NASHUA	29.748	47596.8
LEO517	1995	3.55	2.55	2.17	2.25	2.92	1.39	2.93	1.4	2.62	8.94	6.2	2.25	39.17	Leominster		Central	NASHUA	23.502	37603.2
LEO517	1996	7.35	2.92	2.85	8.46	3.01	2.52	8.86	0.67	7.42	10.53	3.53	7.07	65.19	Leominster		Central	NASHUA	39.114	62582.4
LEO517	1997	3.5	2.99	4.59	4.31	2.57	1.16	3.34	5.42	2.16	2.56	5.59	3.07	41.26	Leominster		Central	NASHUA	24.756	39609.6
LEO517	1998	5.48	5.33	5.62	3.22	7.16	8.94	1.47	2.39	2.24	5.55	3.1	1.41	51.91	Leominster		Central	NASHUA	31.146	49833.6
LEO517	1999	5.69	4.02	4.58	0.78	2.82	1.53	2.58	3.31	7.96	3.33	2.42	2.16	41.18	Leominster		Central	NASHUA	24.708	39532.8
LEO517	2000	3.42	3.38	4.42	6.57	3.2	6.07	4.76	1.74	3.43	2.83	3.98	3.36	47.16	Leominster		Central	NASHUA	28.296	45273.6
LEO517	2001	2.2	2.73	8.55	1.41	2.48	6.46	2.92	1.97	4.57	0.64	0.93	3.08	37.94	Leominster		Central	NASHUA	22.764	36422.4
LEO517	2002	2.76	1.8	5.44	2.41	4.95	4.39	1.21	2.7	3.2	4.19	5.01	5.07	43.13	Leominster		Central	NASHUA	25.878	41404.8
LEO517	2003	2.66	4.54	5.08	3.44	5.01	4.31	1.46	6.31	4.61	5.27	1.93	5.15	49.77	Leominster		Central	NASHUA	29.862	47779.2
LEO517	2004	1.01	1.37	3.53	7.39	3.65	2.07	3.44	3.64	7.46	1.97	4.23	5.07	44.83	Leominster		Central	NASHUA	26.898	43036.8
LEO517	2005	5.17	3.17	4.6	5.54	4.91	4.93	4.42	2.64	2.02	14.61	4.81	4.24	61.06	Leominster		Central	NASHUA	36.636	58617.6
LEO517	2006	5.27	3.05	0.67	2.26	8.25	9.71	3.37	6.08	2.47	6.31	6.98	2.25	56.67	Leominster		Central	NASHUA	34.002	54403.2
LEO517	2007	2.39	2.24	3.54	7.03	4.65	2.6	8.61	1.19	2.74	3.5	3.1	3.84	45.43	Leominster		Central	NASHUA	27.258	43612.8
LEO517	2008	3.05	9.69	5.79	3.97	1.79	4.18	6.54	4.53	9.49	2.06	4.15	6.76	62	Leominster		Central	NASHUA	37.2	59520
LEO517	2009	2.08	1.61	3.02	4.18	3.65	6.95	10.32	3.09	1.22	5.05	4.08	4.28	49.53	Leominster		Central	NASHUA	29.718	47548.8
LEO517	2010	2.96	6.18	13.14	1.55	3.79	3.12	5.24	2.59	2.44	5.48	3	3.54	53.03	Leominster		Central	NASHUA	31.818	50908.8
LEO517	2011	2.77	4.16	4.48	4.71	3.1	6.7	1.39	8.63	7.04	6.23	4.38	4.52	58.11	Leominster		Central	NASHUA	34.866	55785.6
LEO517	2012	2.95	1.81	1.04	3.23	3.68	4.87	1.34	4.27	3.36	6.4	0.94	4.04	37.93	Leominster		Central	NASHUA	22.758	36412.8
LEO517	2013	1.65	4.16	3.5	1.53	6.1	8.24	3.6	2.4	2.04	1.37	3.09	4.3	41.98	Leominster		Central	NASHUA	25.188	40300.8
LEO517	2014	2.76	4.36	4.92	4.54	2.96	2.29	3.82	2.98	1.83	5.53	4.27		40.26	Leominster		Central	NASHUA	24.156	38649.6

Table 1.2 City of Southbridge, MA precipitation data for the last 25 years (inches)

STATION	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual	CITY	Region Co	Region	Basin Name	Gallons/sqaure foot	Gallons/year
SOU430	1990	4.57	4.4	2.24	5.2	7.7	1.6	2.6	5.08	2.08	7.81	2.68	5.54	51.5	Southbridge		Central	QUINEBAUG	30.9	49440
SOU430	1991	3.18	2.28	5.87	3.18	4.3	2.16	3.56	9.57	6.99	3.42	5.4	2.8	52.71	Southbridge		Central	QUINEBAUG	31.626	50601.6
SOU430	1992	2.99	2.58	4.84	3.86	3.22	4.45	4.79	5.37	3.33	3.17	5.93	5.97	50.5	Southbridge		Central	QUINEBAUG	30.3	48480
SOU430	1993	3.34	3.05	6.45	4.26	1.77	1.84	3.34	3.29	7.05	3.95	4.88	6.78	50	Southbridge		Central	QUINEBAUG	30	48000
SOU430	1994	6.02	2.98	6.44	2.76	3.9	3.23	3.22	6.7	4.89	1.06	5.09	4.38	50.67	Southbridge		Central	QUINEBAUG	30.402	48643.2
SOU430	1995	4.58	3.29	2.97	2.56	2.76	1.92	5.15	2.31	3.51	9.67	5.36	2.58	46.66	Southbridge		Central	QUINEBAUG	27.996	44793.6
SOU430	1996	8.42	3.29	3.48	8.2	3.47	4.11	7.19	2.93	6.71	6.09	4.31	8.26	66.46	Southbridge		Central	QUINEBAUG	39.876	63801.6
SOU430	1997	4.45	2.24	3.99	5.63	2.99	2.53	2.44	5.34	1.33	2.42	7.29	3.57	44.22	Southbridge		Central	QUINEBAUG	26.532	42451.2
SOU430	1998	4.99	4.09	7.72	3.77	4.7	7.49	5.38	3.69	3.57	5.79	2.43	1.62	55.24	Southbridge		Central	QUINEBAUG	33.144	53030.4
SOU430	1999	7.42	4.15	6.74	1.17	4.25	0.39	4.42	1.78	8.12	4.75	1.56	3.01	47.76	Southbridge		Central	QUINEBAUG	28.656	45849.6
SOU430	2000	3.89		4.42	7.12	4.31	5.96	5.57	2.88	3.56	1.32	3.79	6.04	48.86	Southbridge		Central	QUINEBAUG	29.316	46905.6
SOU430	2001	3.25	2.8	6.31	3.97	3.54	5.79	2.94	3.33	4.08	0.66	1.28	2.95	40.9	Southbridge		Central	QUINEBAUG	24.54	39264
SOU430	2002	1.67	1.35	4.69	3.89	6.38	4.16	2.81	5.27	3.33	3.92	5.13	5.75	48.36	Southbridge		Central	QUINEBAUG	29.01	46416
SOU430	2003	3.06	4.12	3.47	2.99	4.96	6.74	2.22	4.91	5.03	6.79	2.53	5.44	52.26	Southbridge		Central	QUINEBAUG	31.356	50169.6
SOU430	2004	1.78	1.77	2.88	7.36	4.12	1.47	6.3	4.7	9.39	1.85	4.07	6.35	52.04	Southbridge		Central	QUINEBAUG	31.224	49958.4
SOU430	2005	5.93	3.55	4.1	7.44	3.06	1.41	5.14	3.37	2.74	19.39	5.04	4.08	65.25	Southbridge		Central	QUINEBAUG	39.15	62640
SOU430	2006	5.4	2.98	0.52	2.57	7.89	12.32	3.21	5.32	1.8	6.86	6.47	2.31	57.65	Southbridge		Central	QUINEBAUG	34.59	55344
SOU430	2007	3.06	2.91	5.07	8.08	3.83	2.38	3.34	1.84	1.29	3.74	3.43	5.23	44.2	Southbridge		Central	QUINEBAUG	26.52	42432
SOU430	2008	2.55	10.06	5.34	4.68	2.31	4.6	7.32	5.01	10.32	3.02	3.7	8.53	67.44	Southbridge		Central	QUINEBAUG	40.464	64742.4
SOU430	2009	3.94	1.77	3.49	4.49	3.94	4.33	9.39	3.19	1.82	5.24	3.09		44.69	Southbridge		Central	QUINEBAUG	26.814	42902.4
SOU430	2010	3.81	6.77	9.44	1.68	3.21	4.27	4.25	3.84	1.68	8.05	3.78	4.52	55.3	Southbridge		Central	QUINEBAUG	33.18	53088
SOU430	2011	4.8	4.48	5.34	5.6	4.62	6.75	2.7	13.44	7.91	6.04	2.93	5.57	70.18	Southbridge		Central	QUINEBAUG	42.108	67372.8
SOU430	2012	3.03	0.81	2.14	4.11	3.65	5.4	3.12	5.57	5.63	4.97	1.21	6.07	45.71	Southbridge		Central	QUINEBAUG	27.426	43881.6
SOU430	2013	2.14	3.87	3.04	1.58	6.01	11.22	3.38	3.91	3.78	2.7	3.78	4.63	50.04	Southbridge		Central	QUINEBAUG	30.024	48038.4
SOU430	2014	3.52	4.18	5.34	4	4.9	1.78	3.74	2.86	1.39	5.53	4.68		41.92	Southbridge		Central	QUINEBAUG	25.152	40243.2

Table 1.3 City of Worcester, MA precipitation data for the last 25 years (inches)

STATION	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual	CITY	Region Co	Region	Basin Name	Gallons/sqaure foot	Gallons/year
WORNWS	1990	3.75	3.88	1.52	4.78	7.65	1.74	2.44	6.84	1.73	10.19	2.41	5.46	52.39	Worcester	Yes	Central	BLACKSTONE	31.434	50294.4
WORNWS	1991	2.98	2.08	4.92	5.04	4.16	3.06	2.78	8.01	6.4	3.44	5.47	2.89	51.23	Worcester	Yes	Central	BLACKSTONE	30.738	49180.8
WORNWS	1992	3.01	2.51	4.15	2.59	2.54	4.68	5.25	4.83	3.58	2.36	4.94	4.61	45.05	Worcester	Yes	Central	BLACKSTONE	27.03	43248
WORNWS	1993	2.56	2.38	5.46	4	1.79	2.36	3.34	1.9	8.85	3.88	4.85	5.11	46.48	Worcester	Yes	Central	BLACKSTONE	27.888	44620.8
WORNWS	1994	5.11	1.86	5.38	2.73	5.87	2.48	3.09	7.64	4.84	1.24	4.54	4.81	49.59	Worcester	Yes	Central	BLACKSTONE	29.754	47606.4
WORNWS	1995	3.71	2.86	1.85	1.3	2.39		4.17	1.62	3.15	8.65	4.61	1.3	35.61	Worcester	Yes	Central	BLACKSTONE	21.366	34185.6
WORNWS	1996	6.7	2.83	2.16	6.44	3.26		6.49		6.07	5.81	2.93		42.69	Worcester	Yes	Central	BLACKSTONE	25.614	40982.4
WORNWS	1997	3.25	1.71	4.66	3.22	2.72	1.6	2.97	4.34	1.44	2.11	5.5	2.32	35.84	Worcester	Yes	Central	BLACKSTONE	21.504	34406.4
WORNWS	1998	4.59	3.17	5.82	3.3	5.89	9.68	1.76	2.38	1.69	4.93	2.28	1.46	46.95	Worcester	Yes	Central	BLACKSTONE	28.17	45072
WORNWS	1999	6.01	3.38	4.09	0.92	2.8	0.32	3.63	1.87	8.83	3.57	3.38	2.55	41.35	Worcester	Yes	Central	BLACKSTONE	24.81	39696
WORNWS	2000	3.11	2.6	3.82	6.85	3.52	5.85	3.85	2.1	3.02	2.06	3.61	3.62	44.01	Worcester	Yes	Central	BLACKSTONE	26.406	42249.6
WORNWS	2001	1.64	3.07	6.68	0.75	2.26	6.28	1.92	2.41	3.42	0.7	1.36	2.77	33.26	Worcester	Yes	Central	BLACKSTONE	19.956	31929.6
WORNWS	2002	2.47	1.43	4.2	3.58	5.57	4.85	2.65	2.95	3.59	4.39	3.82	4.51	44.01	Worcester	Yes	Central	BLACKSTONE	26.406	42249.6
WORNWS	2003	2.41	4.43	4.06	3.43	4.13	6.16	2.05	5.34	4.26	5.42	2.19	5.71	49.59	Worcester	Yes	Central	BLACKSTONE	29.754	47606.4
WORNWS	2004	1.43	1.45	3.35	6.57	3.27	1.45	4.84	5.07	7.52	2.22	3.93	4.78	45.88	Worcester	Yes	Central	BLACKSTONE	27.528	44044.8
WORNWS	2005	5.84	3.03	4.18	6.49	3.71	1.77	5.02	2.64	2.83	15.56	4.77	3.74	59.58	Worcester	Yes	Central	BLACKSTONE	35.748	57196.8
WORNWS	2006	5.23	3.51	0.5	2.35	6.64	6.91	3.22	4.07	2.37	6.91	7.09	2.49	51.29	Worcester	Yes	Central	BLACKSTONE	30.774	49238.4
WORNWS	2007	3.11	1.73	4.7	8.3	5.12	2.16	4.3	1.01	1.98	3.12	3.24	4.57	43.34	Worcester	Yes	Central	BLACKSTONE	26.004	41606.4
WORNWS	2008	2.45	9.68	5.62	4.24	2.45	5.55	7.97	3.53	9.22	2.62	4.25	5.63	63.21	Worcester	Yes	Central	BLACKSTONE	37.926	60681.6
WORNWS	2009	3.49	1.91	2.81	3.8	2.96	6.51	10.81	2.81	1.87	5.02	3.41	4.68	50.08	Worcester	Yes	Central	BLACKSTONE	30.048	48076.8
WORNWS	2010	3.29	4.47	10.24	1.37	2.86	4.03	2.59	4.36	2.27	6.21	4.26	5.08	51.03	Worcester	Yes	Central	BLACKSTONE	30.618	48988.8
WORNWS	2011	4.1	5.3	5.06	5.54	3.88	6.91	2.2	12.21	7.26	6.11	4.27	5.16	68	Worcester	Yes	Central	BLACKSTONE	40.8	65280
WORNWS	2012	3.03	1.42	1.16	3.12	4	5.53	3.16	6.7	4.8	4.16	1.19	5.11	43.38	Worcester	Yes	Central	BLACKSTONE	26.028	41644.8
WORNWS	2013	1.95	4.93	3.68	1.8	4.45	10.06	2.97	3.18	3.23	1.43	3.62	4.43	45.73	Worcester	Yes	Central	BLACKSTONE	27.438	43900.8
WORNWS	2014	3.11	4.08	5.42	4.44	4.15	1.56	6.28	6	2.72	6.37	4.23		48.36	Worcester	Yes	Central	BLACKSTONE	29.016	46425.6

6.2 California Precipitation results

Table 2.1 Southern California precipitation data for the last 25 years (inches)

Total Monthly Precipation data in Inches															
Southern California(Los Angeles)															
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual(inches)	Gallons/ Sqaure foot	Gallons/year
1990	1.24	3.12	0.17	0.58	1.17	0	0	0.02	0	0	0.19	0	6.49	3.894	6230.4
1991	1.17	4.13	5.92	0.03	0	0.01	0.13	0	0.09	0.37	0	3.22	15.07	9.042	14467.2
1992	1.74	7.96	7.12	0.33	0.04	0	0.08	0	0	0.7	0	4.68	22.65	13.59	21744
1993	11.77	6.61	2.74	0	0.02	0.76	0	0	0	0.16	0.66	0.78	23.5	14.1	22560
1994	0.33	3.21	1.86	0.83	0.28	0	0	0	0	0.19	0.61	1.35	8.66	5.196	8313.6
1995	12.56	1.3	6.98	0.58	0.18	0.6	0.02	0	0	0	0.09	1.34	23.65	14.19	22704
1996	3.16	4.94	2.16	0.71	0.04	0	0	0	0	1.06	1.59	4.09	17.75	10.65	17040
1997	5.58	0.08	0	0	0	0	0	0	0.45	0	2.06	2.52	10.69	6.414	10262.4
1998	4.12	13.68	4.06	0.97	3.1	0.05	0	0	0.01	0	1.32	0.54	27.85	16.71	26736
1999	1.85	0.56	1.24	2.57	0.02	0.98	0	0	0	0	0.44	0.4	8.06	4.836	7737.6
2000	0.88	5.54	2.82	1.49	0	0	0	0.07	0.15	0.98	0	0	11.93	7.158	11452.8
2001	5.59	8.87	1.17	1.11	0	0	0	0	0	0.06	1.42	1.38	19.6	11.76	18816
2002	0.8	0.29	0.32	0.09	0.05	0.01	0	0	0	0.05	2.43	3.31	7.35	4.41	7056
2003	0	4.64	4.32	0.71	1.02	0.01	0	0	0	0.53	0.79	1.35	13.37	8.022	12835.2
2004	0.47	4.89	1.17	0.04	0	0	0	0	0	4.56	0.2	8.77	20.1	12.06	19296
2005	9.32	11.02	2.14	1.05	0.19	0	0	0	0.29	1.35	0.22	1.03	26.61	15.966	25545.6
2006	2.06	2.37	2.87	2.15	0.85	0	0	0	0	0.34	0.16	0.81	11.61	6.966	11145.6
2007	0.19	0.92	0.05	0.74	0	0	0	0	0.52	0.95	0.56	1.73	5.66	3.396	5433.6
2008	7.97	1.64	0.01	0.04	0.11	0	0	0	0	0.02	1.85	2.79	14.43	8.658	13852.8
2009	0.34	3.57	0.33	0.03	0	0.15	0	0	0	2.07	0.01	2.89	9.39	5.634	9014.4
2010	4.94	4.27	0.48	1.65	0.05	0	0	0	0	0.94	0.53	10.23	23.09	13.854	22166.4
2011	0.79	3.29	3.96	0	0.45	0.01	0	0	0	1.17	1.58	1.01	12.26	7.356	11769.6
2012	1.3	0.16	1.75	1.71	0.01	0	0.01	0	0	0.02	1.03	2.16	8.15	4.89	7824
2013	1.18	0.2	0.54	0	0.71	0	0.09	0	0	0.06	0.62	0.2	3.6	2.16	3456
2014	0	3.58	1.18	0.35	0	0	0	0.04	0.01	0.25	0.48	3.88	9.77	5.862	9379.2

Table 2.2 Northern California precipitation data for the last 25 years (inches)

Northen California(Sacremento)															
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual	Gallons/ Sqaure foot	Gallons/year
1990	4.97	2.91	0.93	0.73	2.1	0	0	0	0	0.09	0.43	1.6	13.76	8.256	13209.6
1991	0.36	3.1	6.14	0.29	0.25	0.53	0	0.14	0.04	1.25	0.19	1.6	13.89	8.334	13334.4
1992	1.39	5.47	2.05	0.92	0	0.15	0	0	0	1.31	0.28	4.94	16.51	9.906	15849.6
1993	8.63	4.94	2.39	0.63	1.14	1.26	0	0	0	0.47	2.15	1.75	23.36	14.016	22425.6
1994	2.12	3.15	0.05	0.67	1.68	0	0	0	0	0	0.71	2.68	11.06	6.636	10617.6
1995	8.81	0.2	8.13	1.46	1.06	0.47	0	0	0	0	0	5.49	25.62	15.372	24595.2
1996	4.16	5.49	1.73	1.25	0.79	0	0	0	0	0.67	1.97	6.39	22.45	13.47	21552
1997	9.05	0.28	0.34	0.18	0.35	0.59	0	0.32	0.16	0.82	4.56	2.91	19.56	11.736	18777.6
1998	6.4	9.95	2.47	1.05	2.98	0.58	0	0	0.23	0.76	2.84	0.58	27.84	16.704	26726.4
1999	2.63	4.45	1.5	0.89	0.07	0.03	0	0	0	0.18	1.63	0.06	11.44	6.864	10982.4
2000	6.49	8.49	2.03	1.39	1.17	0.04	0	0	0.09	1.62	0.68	0.59	22.59	13.554	21686.4
2001	3.75	4.57	2.04	1.5	0	0.08	0	0	0.5	0.36	2.43	6.27	21.5	12.9	20640
2002	2.19	1.13	2.87	0.12	2.07	0	0	0	0	0	2.34	6.26	16.98	10.188	16300.8
2003	1.29	1.29	1.87	2.53	1.17	0	0	0.57	0	0.04	1.52	4.23	14.51	8.706	13929.6
2004	2.11	5.01	0.48	0.09	0.17	0	0	0	0.16	2.71	2.69	4.14	17.56	10.536	16857.6
2005	3.83	2.33	3.3	0.84	1.23	0.66	0	0	0	0.15	0.85	8.98	22.17	13.302	21283.2
2006	2.53	2.09	5.29	3.27	0.3	0	0	0	0	0.16	1.12	3.01	17.77	10.662	17059.2
2007	0.05	4.44	0.35	1.34	0.41	0	0.01	0	0.06	1.05	0.85	3.17	11.73	7.038	11260.8
2008	6.67	1.81	0.05	0	0.04	0	0	0	0	0.84	2.38	1.51	13.3	7.98	12768
2009	1.41	5.07	2.09	1.46	1.01	0.56	0	0	0.14	3.24	0.26	3.64	18.88	11.328	18124.8
2010	4.79	2.29	2.98	2.65	0.75	0	0	0	0.01	1.43	2.39	5.55	22.84	13.704	21926.4
2011	1.67	3.39	6.95	0.06	1.02	1.5	0	0	0.01	1.33	0.74	0.27	16.94	10.164	16262.4
2012	2.43	0.92	4.06	2.42	0	0.03	0.03	0	0	1.14	3.97	6.15	21.15	12.69	20304
2013	0.96	0.36	1.38	0.69	0.3	0.22	0	0	0.59	0	0.88	0.43	5.81	3.486	5577.6
2014	0.15	4.14	1.77	1.83	0	0	0.01	0	0.46	0.53	1.25	8.6	18.74	11.244	17990.4

Table 2.3 Central California precipitation data for the last 25 years (inches)

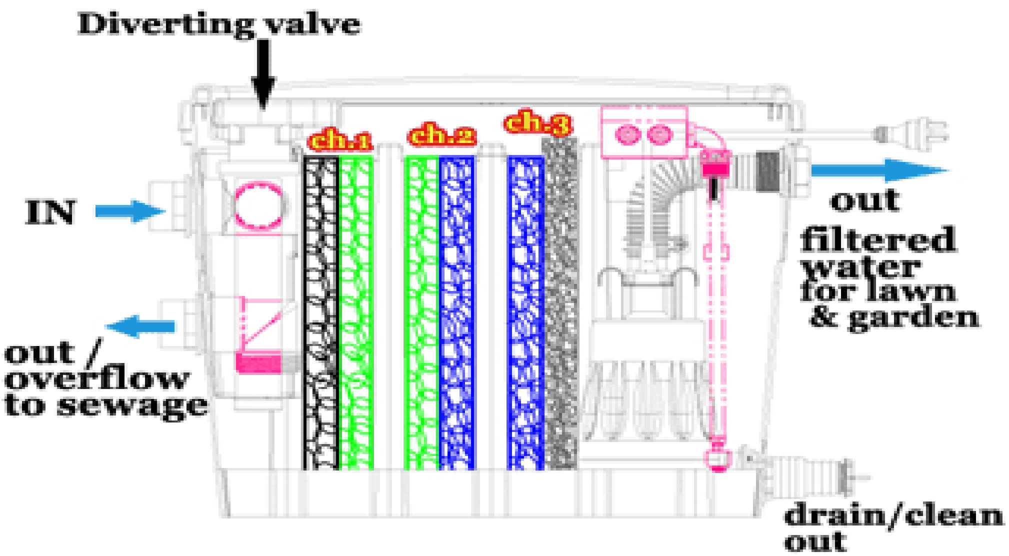
Central California(Fresno)															
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual	Gallons/ Sqaure foot	Gallons/year
1990	2.82	1.33	0.67	0.92	1.65	0	0	0	0.15	0.05	0.46	0.68	8.73	5.238	8380.8
1991	0.13	1.01	7.24	0.02	0.03	0	0	0	0	0.8	0.04	1.22	10.49	6.294	10070.4
1992	1.94	4.73	2.14	0.18	0	0	0.22	0	0	2.19	0	2.68	14.08	8.448	13516.8
1993	5.18	2.44	1.76	0.2	0.25	1.61	0	0	0	0.12	1.16	1.03	13.75	8.25	13200
1994	1.15	1.92	0.52	1.36	1.3	0	0	0	0.2	0.77	1.57	1.33	10.12	6.072	9715.2
1995	5.42	0.93	5.88	1.08	1.19	0.66	0.01	0	0	0	0	2.08	17.25	10.35	16560
1996	2.07	3.57	1.52	1.17	0.38	0.08	0	0	0	1.97	1.94	4.27	16.97	10.182	16291.2
1997	3.53	0.17	0.1	0	0	0.01	0	0	0.15	0.07	2.66	0.99	7.68	4.608	7372.8
1998	3.4	4.89	3.44	1.26	1.37	1.93	0	0	0.15	0.16	0.43	0.62	17.65	10.59	16944
1999	2.82	1.18	0.49	0.93	0.03	0.2	0	0.01	0	0	0.48	0.03	6.17	3.702	5923.2
2000	3.15	6.12	1.35	1.16	0.05	0.56	0	0	0.32	2.45	0.01	0.07	15.24	9.144	14630.4
2001	2.66	2.22	0.96	1.87	0	0	0.08	0	0	0.29	1.99	1.95	12.02	7.212	11539.2
2002	0.76	0.4	0.95	0.21	0.38	0.02	0	0	0	0	1.78	2.25	6.75	4.05	6480
2003	0.4	1.22	0.63	2.84	0.68	0	0	0.04	0	0	0.4	2.93	9.14	5.484	8774.4
2004	0.88	1.69	1.54	0.03	0.07	0	0	0	0	2.45	0.81	3.16	10.63	6.378	10204.8
2005	2.42	2.3	2.51	0.56	1.62	0.01	0	0	0.04	0.05	0.17	2	11.68	7.008	11212.8
2006	3.4	0.54	4.73	3.27	0.36	0	0	0	0	0.08	0.23	1.33	13.94	8.364	13382.4
2007	0.59	2.29	0.97	0.49	0.05	0	0	0.02	0.02	0.2	0.09	2.31	7.03	4.218	6748.8
2008	3.32	2.12	0.02	0	0.3	0	0.01	0	0	0.23	1.37	1.09	8.46	5.076	8121.6
2009	1.02	2.43	0.24	0.72	0.46	0.2	0	0	0.01	1.39	0.2	2.41	9.08	5.448	8716.8
2010	2.05	2.94	0.96	2.19	0.21	0	0	0	0	0.44	1.8	5.92	16.51	9.906	15849.6
2011	1.71	1.6	3.46	0.32	0.35	1.91	0	0	0	0.9	0.67	0	10.92	6.552	10483.2
2012	1.38	0.75	2.43	2.02	0	0	0	0	0	0.25	1.11	2.03	9.97	5.982	9571.2
2013	0.58	0.89	0.65	0.09	0.07	0	0	0	0.01	0.03	0.54	0.15	3.01	1.806	2889.6
2014	0.57	2.11	0.62	0.74	0.04	0	0.01	0	0.18	0.5	0.4	2.29	7.46	4.476	7161.6

6.3 System used to convert rainwater to reusable water

After all of my research I began looking for a pump with 110V and that could handle 40psi, and I was also searching for filters as well. I found that using a device called a *"first flush diverter"* can remove the first water that comes out of the storage tank filled with rainwater, which may have been sitting in there for a while, may help avoid some of the contaminants in the tank (“Center of disease control and prevention”, 2013). Also found a tool you can use to filter this rainwater in the storage tank which includes a pump and it is called Aqua2Use Greywater Recycling Systems as portrayed in *Figure 5.* I showed the filter to Ryan Cain, who has had 8 years of experience in dealing with water treatment throughout Massachusetts, and he advised me that the filter was too complicated for the project.

Figure 5: Aqua2Use Greywater Recycling System, a Tool used to filter Rainwater, includes a pump.

Photo: Rain Harvest



Another option for pumps included a Cistern pump (*figure 6*), which was also too complicated but it had a small screen that only allowed really small particles through. Therefore, it came with a filtration system already installed in it. The pump was submersible as well, that means it can also go into water, which was too high tech for the project that we needed it for. However if we wanted to do the additional work, to order the pump; I would have called the locations below and given them the item number to place the order.

Hingham MA. Weymouth Company (781-749-5770),

Back up. AaPump Company (781-826-2341),

ORDER Number: (90301005) (10 gpm/ 115v)

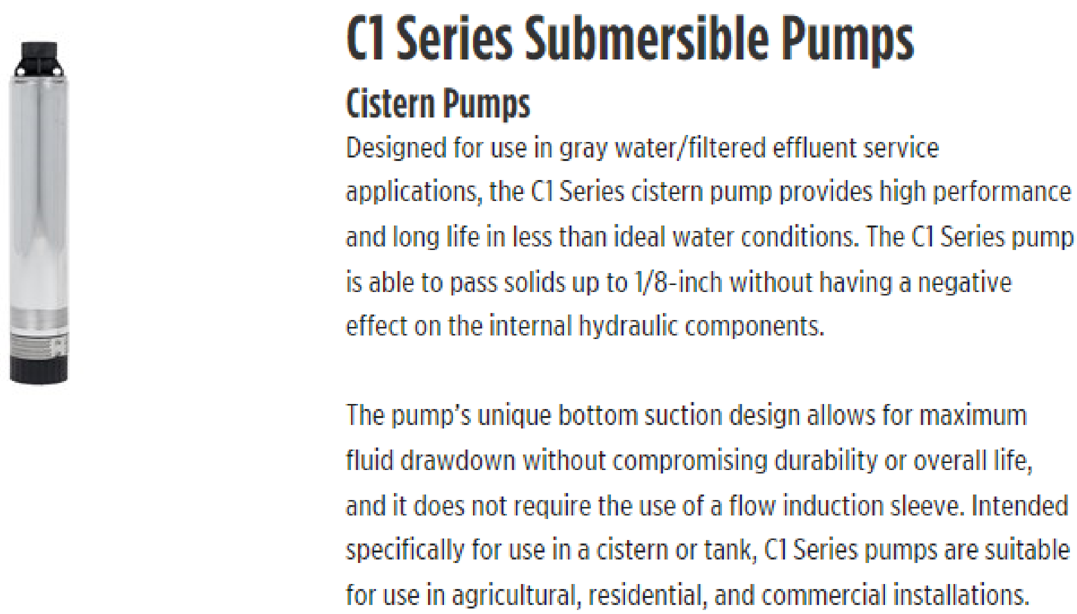


Figure 6: Portrays a cistern submersible pump

Photo: Franklin Water

6.4 Solution (a less complicated system)

After tons of research I found a project that was done for Winthrop Elementary School in Hamilton, September 2006. Winthrop Elementary school wanted to harvest rainwater for irrigation purposes, and they had a company called Rainwater Recovery Inc, install their pumps. The project also included funding installations of 39 rainwater harvesting systems on residential properties in Wilmington, Massachusetts. The systems consisted of a storage tank, a pressure pump to aid in water distribution, a spigot for a hose, and a water meter to measure flow, as shown in *figure 7*

(“What is Ground Water”, 2015). Two different sizes of storage tanks were installed: 200-gallon tanks (28 systems) and 800-gallon tanks (11 systems) (“What is Ground Water”, 2015).

Figure 7: Example of a rainwater harvesting system used in one of the homes in Wilmington

Photo: USGS

This was exactly the kind system we needed, because it was extremely simple and least cost affective. However instead of using it for irrigation, my advisor wanted to use it for connecting it back to his home for domestic purposes such as laundry and flushing the toilet. He also wants one hooked up in his garage for washing his car, particularly for testing purposes before using it for in-home purposes.

Expected Process for house: the expected process for the house would be extremely similar to the system shown in *Figure 8*, an 800 gallon system for $3,440 each.

House → Gutter→Down spout→PVC pipe (in line rainwater FILTER that would go in line with the pipe) → TANK→Another PVC pipe or Spigot or interior pump (this is the step where a Real Plumber comes in and connects whatever he needs to, from the tank to whatever plumbing system that runs through the toilet and laundry so you could use it).

Figure 8: an 800 gallon rainwater harvesting system

Photo: USGS

Expected process for washing a car through a Garden hose: would probably be best to use the 200-gallon system which cost $1,375 each, such as the one shown above in *Figure 7*.

House→ Hose connected to house→PVC pipe→Tank→Spigot→ another water hose or something else that you can use to wash your car.

7 Conclusion

The main goal for capturing rainwater, is to use that water for other purposes such as washing clothes, showering, flushing the toilet and continue to use fresh tap water for drinking. Also rainwater harvesting systems such as the one used in this project, are designed to capture runoff rainwater from rooftops or rain gutters and store the water for other uses, such as lawn and garden watering. Capturing Rainwater for domestic purposes is intended to reduce demand on public water supplies by replacing drinkable water with rainwater. Capturing Rainwater for other uses can also save you abundant of money, because you can store the rainwater and continue using it throughout the year. The local community also saves money because they do not have to treat the excess rainwater that is being captured. While working on this project, I learned a lot about the certain kind chemicals in rainwater, the advantages of rainwater and most importantly found out a system that residents can use regularly to help save them money on their water bill. It was great to be able to use what I have learned throughout my coursework at Worcester Polytechnic Institute to complete such an important project that can better the lives of the population and their communities.

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